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AN INTERCOMPARISON OF DETECTORS FOR MEASUREMENT OF BACKGROUND RADIATION

Sven P. Nielsen and Lars Bøtter-Jensen

Abstract. Measurements of the background radiation were made in 1978 at 14 locations with a high-pressure ionization chamber, thermoluminiscence dosimeters (TLD's), two NaI(Tl) detectors, and a Ge(Li) spectrometer system. Simultaneous measurements with the ionization chamber and the spectrometer system provide reliable estimates of the total background exposure rate, of the individual contributors to the terrestrial exposure rate, and of the exposure rate from the secondary cosmic radiation. The TLD results agree with those of the ionization chamber. The NaI(Tl) detector results show that accurate estimates of the terrestrial exposure rate can be obtained if empirical corrections are applied.

INIS descriptors: BACKGROUND RADIATION; CALIBRATION; COMPARITIVE EVALUATIONS; COSMIC RADIATION; IONIZATION CHAMBERS; LI-DRIFTED GE DETECTORS; NAI DETECTORS; RADIATION DOSES; THERMOLUMINESCENT DOSEMETERS.

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CONTENTS

1. INTRODUCTION

In the Health Physics Department several different instruments are currently used for country-wide measurements of the exposure rate from the penetrating background radiation.

The detectors comprise thermoluminescence dosimeters, a high-pressure ionization chamber, a 11.4 x 5.1-cm Na(Tl) detector, a 7.6 x 7.6-cm NaI(Tl) detector and a portable Ge(Li) detector.

The present study was initiated in order to provide a systematic intercomparison of the results from the instruments which show wide variations of response to the background radiation.

2. DETECTORS

2.1. Thermoluminescence dosimeters (TLD's)

The TL data presented were obtained with hot-pressed solid LiF dosimeters, Harshaw TLD-700 (3 × 3 × 0.8 mm). A main feature of LiF is, in addition to an excellent stability, the low-Z number resulting in a very small change in response per roentgen over a wide energy range.

The exposure rates 1 meter above the ground surface were determined by Risø standard TLD units, each containing 3 LiF dosimeters. The Risø standard TLD unit is a moulded plastic holder which contains the solid TL dosimeters in depressions, together with a binary hole code used for automatic processing. A sandwich shielding of 1-mm Al is provided to obtain electron equilibrium. The TLD system is described in detail by Bøtter-Jensen et al. (1973).

The TLD units integrated the total exposure including cosmic radiation and terrestrial γ-radiation over a 5-month period and each reading was determined from the mean value of the 3 individual dosimeter responses. The mean responses were normalized to exposure rates.

Calibration reference exposures were obtained from a 5-Ci ^{60}Co source intercalibrated with an international standard ^{60}Co source (The State Institute of Radiation Protection, Stockholm) by means of a secondary standard dosemeter (Farmer dosemeter).

2.2. High-pressure ionization chamber

The high-pressure ionization chamber is a Reuter-Stokes model RSS-111 purchased in 1975.

The ionization chamber was developed by the Health and Safety Laboratory of the United States Atomic Energy Commission. De Campo et al. (1972) reported a thorough investigation of this type of ionization chamber system including responses to cosmic radiation and γ-radiation. The ionization chamber yields environmental exposure rates equivalent to free air ionization rates.

The model RSS-111 consists of one unit containing the chamber itself, which is a 25-cm diameter steel sphere filled with argon gas at a pressure of 20 atmospheres and another unit with electrometer, different output facilities, and batteries. Outputs for the present chamber comprise a digital integrator with a resolution of 1 μR h^{-1}, and a magnetic tape recorder which records the LED display value at preset time intervals (5, 10, and 40 s). The latter system allows the data to be transferred to the B6700 computer at Risø for subsequent analyses.

The ionization chamber is calibrated with a standardized 1 mCi ^{226}Ra source. The source activity is certified by Amersham to an accuracy of ± 0.5%. Calibration is performed by placing the chamber and the source on two vertical wooden poles situated far from buildings. The height of the poles and the distance between them are 3 m ensuring an exposure rate of about 100 μR h^{-1} from the source and a relatively small contribution of scattered γ-rays from the ground. The latter contribution (2%) is estimated from numerical calculations by making use of the differential γ-ray dose albedo for concrete, which is considered as an acceptable approximation of soil in this context. The γ-ray response of the ionization chamber is thus calibrated by adjusting the observed exposure rate from the source to equal the exposure rate calculated from the specific γ-ray constant for ^{226}Ra of 0.825 $Rm^2\ h^{-1}g^{-1}$ plus the above-mentioned correction from scattered radiation.

Measurements of environmental exposure rates are typically made using sampling intervals of 5 s for the magnetic tape recorder. As described by DeCampo et al. a 3% correction is applied to the data in order to account for the difference in spectral composition of γ-rays from a ^{226}Ra source and from a typical environmental radiation field. The correction applies to a photon spectrum 1 m above ground calculated for environmental sources of ^{40}K, ^{232}Th, and ^{238}U assuming the component exposure rates are in the ratios 0.3 : 0.5 : 0.2 for potassium, thorium, and uranium, respectively. An average exposure rate is calculated for the measuring period.

2.3. NaI(Tl) detector (11.4 ×5.1 cm)

This detector has been used since 1962 for routine measurements of the γ-background radiation. The detector system consists of a digital scaler and a closed housing containing the NaI crystal and the photomultiplier. The scaler records the number of pulses from the photomultiplier in a preset time interval; the scaler discrimination level is adjusted to an arbitrary low value corresponding to a counting threshold of 20 keV.

During measurements the detector is placed on a tripod 1 m above ground. Power is supplied from a 12 V battery in a motor vehicle through a 20-m cable.

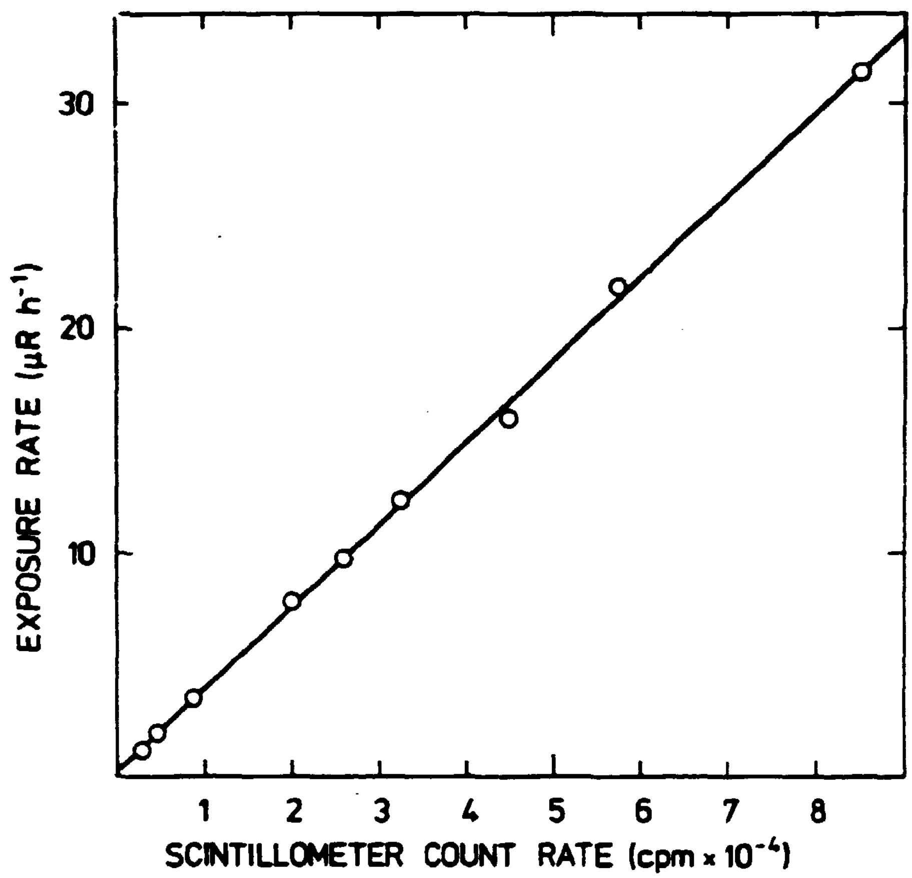


Fig. 2.3. Example of calibration curve for 11.4 x 5.1-cm NaI(Tl) detector.

The detector mainly registers the γ-rays from the background radiation, but also the cosmic-ray secondaries as well as the potassium in the photomultiplier assembly cause an inherent low count rate.

At each location a 3-min measurement is made at 3 different places which are spaced from each other as much as the power cable permits, thus providing information on the homogeneity of the radiation field. The overall average count rate is used as the final result.

The detector is calibrated with the certified 1 mCi ^{226}Ra source, by placing the source at various distances from the detector and noting the increase in detector count rate above the background. A calibration curve is obtained by plotting the calculated exposure rate (using the specific γ-ray constant) versus the increase in count rate. A typical example is shown in Fig. 2.3.

The calibration curve is used for converting the observed count rates to exposure rates. In this way a systematic error is introduced caused by the inherent detector count rate.

2.4. NaI(Tl) detector (7.6 × 7.6 cm)

The detector is placed in a tin canister lined with 5-cm expanded polystyrene to reduce the influence of temperature variations on the photomultiplier tube. During measurements the detector is placed on a tripod 1 m above ground and connected to a multichannel analyser through 50-m cables. The detector is used as a total count scintillometer with a counting threshold of about 0.4 MeV, which is accurately determined from the γ-spectrum. The analyser is mounted in a motor vehicle which has been especially equipped for transport of the spectrometer system and for supplying electrical power to the instruments. Counting times varies from 1000 to 3000 s depending on the intensity of the γ-background.

The detector was calibrated with the high-pressure ionization chamber, from previous measurements. The relation between exposure rate ($\dot{X}$) from the γ-background and the detector count rate (n) is expressed as

$$\dot{X}(\mu R\ h^{-1}) = 0.105 \cdot n(\mathrm{cps}).$$

2.5. Ge(Li) detector

The Ge(Li) detector is used in a mobile spectrometer system, which is described in detail elsewhere (Nielsen, 1977).

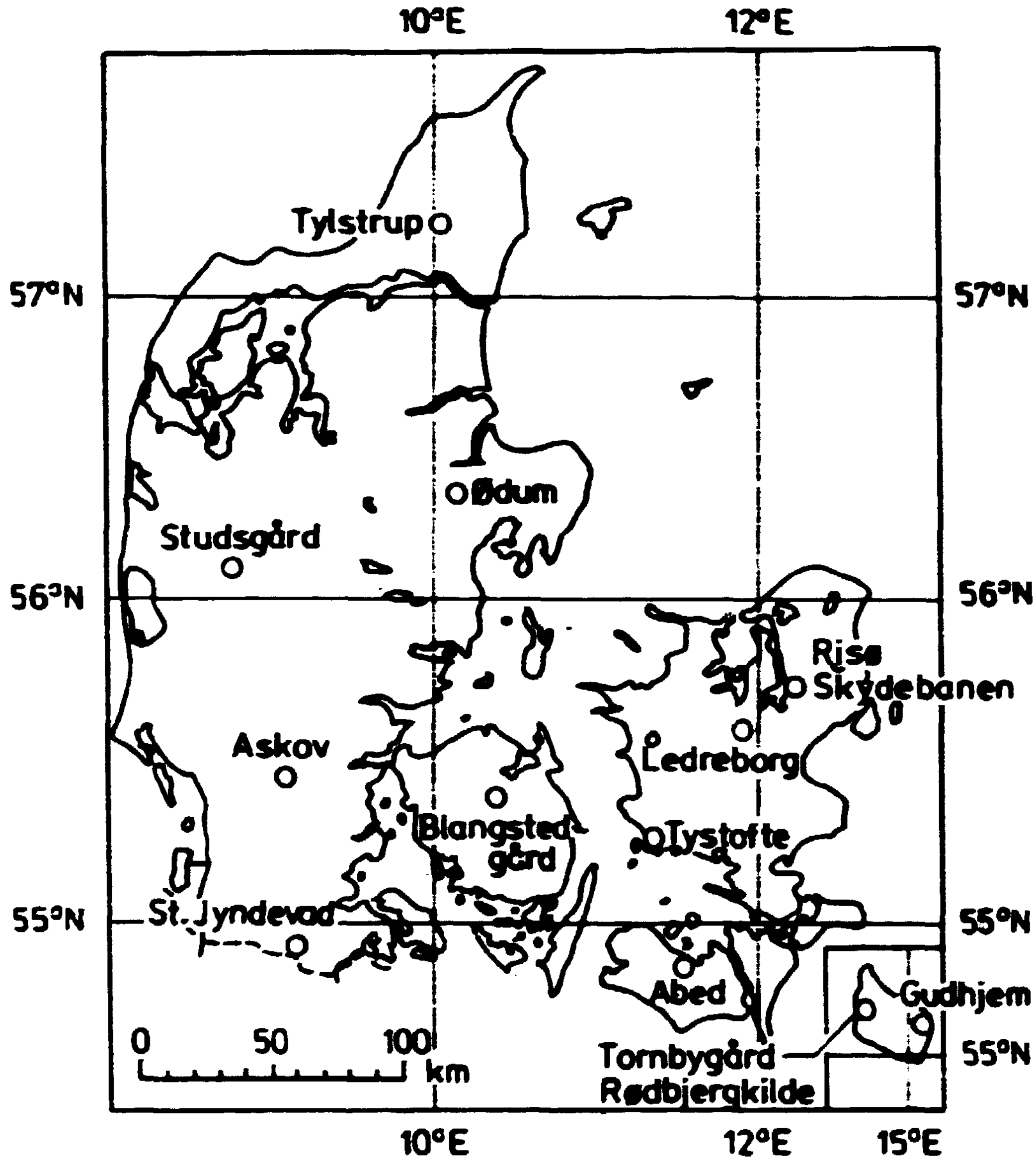
The detector has a resolution of 2.0 keV at 1.33 MeV and an efficiency of 17%, and it is mounted vertically underneath the liquid nitrogen dewar flask. During measurements the detector is placed on a tripod 1 m above ground and connected to the electronic instruments in the motor vehicle through 50-m cables. The γ-spectra are recorded in the multichannel analyser making full use of the 4-k memory, subsequently punched on paper tape and transferred to the B6700 computer for analyses.

Counting times are typically 7000 s.

The Ge(Li) spectrum evaluation is based on a technique developed by Beck (1972). The calibration includes the experimental determination of detector caracteristics (efficiency and angular response) and knowledge of the relations between concentrations in the ground of γ-emitting radionuclides, flux densities of unattenuated γ-rays, and corresponding exposure rates.

3. MEASURING PROGRAMME

Near Risø a location was selected for a long-term study of the variations with time of the background radiation. The instrumentation comprised TLD's and the high-pressure ionization chamber. The latter yields detailed information on the variation of exposure rate with time and permits also an assessment of the integrated exposure over a period of time.



<u>Fig. 3.1.</u> Locations for short-term measurements of background radiation.

A total of 14 locations were chosen for short-term observations, selected mainly among the State experimental farms which have representative background radiation levels for Denmark. The locations are shown in Fig. 3.1. The instrumentation included all the detectors mentioned previously, and it was the intention to perform as many silmultaneous measurements as practicable in order to get a good basis for comparison.

The measurements were made in 1978.

4. RESULTS

The individual instrument results are presented in tables. In order to facilitate assessments of precisions and accuracies of exposure rates, the results are also shown in figures for comparison with ionization chamber results. Regression lines have been fitted to the data and the regression coefficients are presented with uncertainties representing standard deviations

The statistical analyses have been calculated with the STATDATA computer program developed by Lippert (1975).

4.1. Ionization chamber results

The ionization chamber results are shown in Table 4.1.

A systematic constant output error of 0.3 $\mu R\ h^{-1}$ found in connection with the zero setting was corrected for by subtracting this value from all the mean exposure rates calculated from the magnetic tape data.

Table 4.1. Ionization chamber measurements of the total background radiation ($\mu R\ h^{-1}$).

Location	April	June	September	Mean
Tylstrup	7.0	7.2	7.3	7.2
Studsgård	6.0	6.3	6.0	6.1
Ødum	7.5	7.8	8.1	7.8
Askov	6.9	7.1	7.1	7.0
St.Jyndevad	5.5	5.5	5.6	5.5
Blangstedgård	7.9	8.2	8.0	8.0
Skydebanen	7.7	7.8	7.5	7.7
Risø	8.5	8.4	8.6	8.5
Ledreborg	8.4	8.5	8.4	8.4
Tystofte	8.1	8.6	8.0	8.2
Abed	8.3	8.7	8.7	8.6
Gudhjem	(9.5)	9.7	9.7	9.6
Tornbygård	(8.9)	9.2	9.0	9.0
Rødbjergkilde	(9.3)	9.6	9.2	9.4
Mean	7.9	8.0	7.9	7.9

Numbers in brackets estimated from analysis of variance

4.2. TLD results

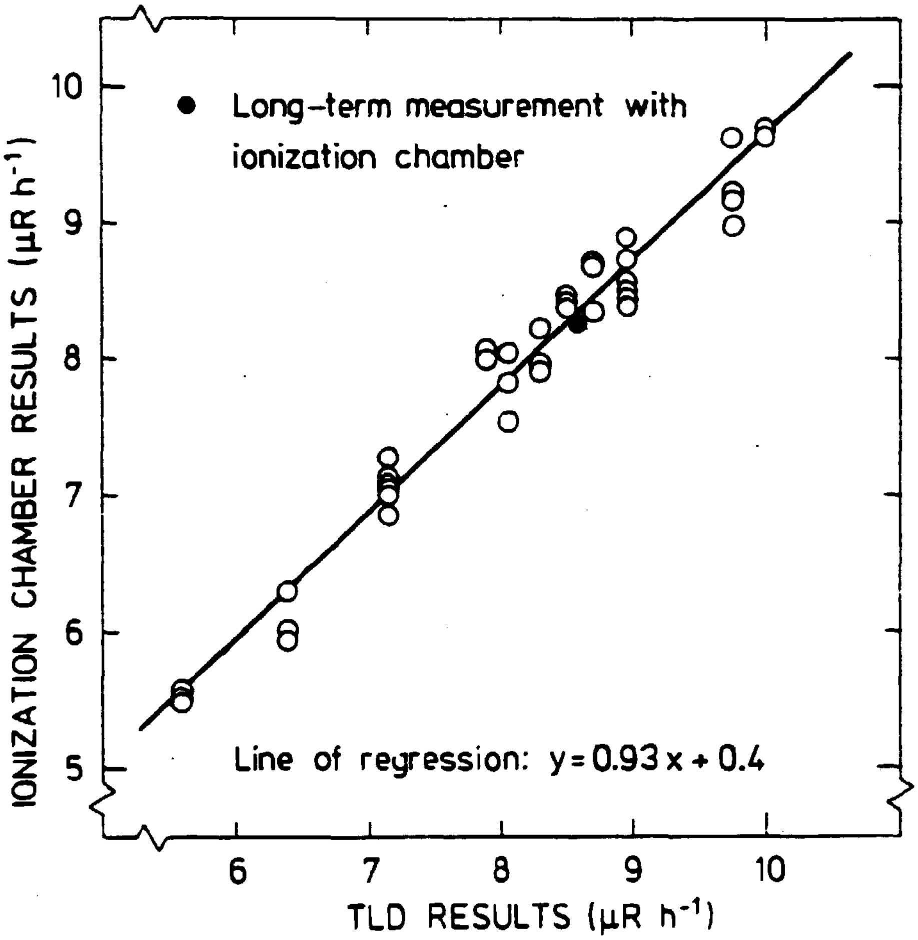
The TLD results which represent a 5-month integration time are shown in Table 4.2 and Fig. 4.2.1.

The regression line in Fig. 4.2.1 is of the type $y = \alpha x + \beta$ with the coefficients $\alpha = 0.93 \pm 0.04\ \mu R\ h^{-1}$ per $\mu R\ h^{-1}$ and $\beta = 0.4 \pm 0.3\ \mu R\ h^{-1}$. The slope α is not significantly different from unity and the intercept β not significantly different from zero at the 5% level. Therefore, the coefficients do no indicate any significant difference between the two types of results.

Table 4.2. TLD measurements of the total background radiation (μR h^{-1}).

Location	April-September
Tylstrup	7.2
Studsgård	6.4
Ødum	8.1
Askov	7.2
St.Jyndevad	5.6
Blangstedgård	8.3
Skydebanen	-
Risø	9.0
Ledreborg	8.5
Tystofte	7.9
Abed	8.7
Gudhjem	10.0
Tornbygård	9.8
Rødbjergkilde	9.8
Mean	8.2

In the long-term study with the ionization chamber, the TLD integration time was 9 weeks of which 76% was covered with the ionization chamber. The TLD mean exposure rate was calculated to 8.6 μR h^{-1} and the ionization chamber mean exposure rate was 8.3 μR h^{-1}. The result is shown in Fig. 4.2.1 where it compares well with the other results obtained. An excerpt of the long term ionization chamber results is shown in Fig. 4.2.2.



<u>Fig. 4.2.1.</u> Results of TLD measurements (μR h^{-1}) versus results of ionization chamber measurements (μR h^{-1}).

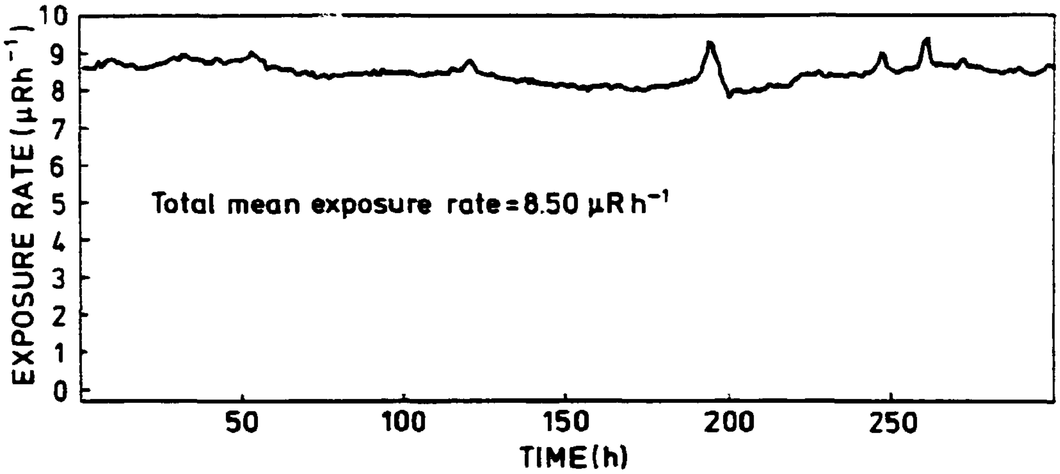


Fig. 4.2.2. Excerpt of long-term ionization chamber measurement (μR h^{-1}).

4.3. NaI(Tl) detector results

The results for the 11.4 × 5.1-cm detector are shown in Table 4.3.1 and for the 7.6 × 7.6-cm detector in Table 4.3.2. The results are shown versus the ionization chamber results in Figs. 4.3.1 and 4.3.2. The regression lines are of the type $y = \alpha(x-\beta)$, and for the 11.4 × 5.1-cm detector the coefficients are $\alpha = 0.96 \pm 0.06$ μR h^{-1} per μR h^{-1} and $\beta = 2.5 \pm 0.4$ μR h^{-1}; for the 7.6 × 7.6-cm detector $\alpha = 1.03 \pm 0.04$ μR h^{-1} per μR h^{-1} and $\beta = 3.2 \pm 0.2$ μR h^{-1}.

It is noted that the results from the 11.4 × 5.1-cm detector display a lower precision than those from the 7.6 × 7.6-cm detector, and that none of the slopes depart significantly from unity.

Table 4.3.1. Terrestrial exposure rates measured with the 11.4 x 5.1-cm NaI(Tl) detector ($\mu R\ h^{-1}$).

Location	April	June	September	Mean
Tylstrup	4.5	4.2	4.1	4.3
Studsgård	3.5	3.5	3.2	3.4
Ødum	4.7	5.1	5.1	5.0
Askov	4.2	4.2	4.5	4.3
St.Jyndevad	3.2	2.4	2.5	2.7
Blangstedgård	5.5	6.7	4.8	5.7
Skydebanen	5.8	4.8	4.6	5.1
Risø	5.4	5.7	5.9	5.7
Ledreborg	6.3	5.4	5.7	5.8
Tystofte	6.1	5.5	5.1	5.6
Abed	6.5	5.8	6.1	6.1
Gudhjem	(7.1)	6.9	6.7	6.9
Tornbygård	(6.7)	6.6	6.2	6.5
Rødbjergkilde	(6.2)	6.1	5.7	6.0
Mean	5.4	5.2	5.0	5.2

Numbers in brackets estimated from analysis of variance

Table 4.3.2. Terrestrial exposure rates measured with the 7.6 x 7.6-cm NaI(Tl) detector (μR h^{-1}).

Location	June	September	Mean
Tylstrup	4.2	3.8	4.0
Studsgård	3.2	2.8	3.0
Ødum	4.9	4.6	4.8
Askov	3.8	3.4	3.6
St.Jyndevad	2.2	2.8	2.6
Blangstedgård	5.5	4.9	5.2
Skydebanen	4.7	4.6	4.6
Risø	5.7	5.7	5.7
Ledreborg	5.5	5.5	5.5
Tystofte	5.1	5.0	5.1
Abed	5.5	5.5	5.5
Gudhjem	6.9	6.5	6.7
Tornbygård	6.2	5.8	6.0
Rødbjergkilde	(6.3)	6.1	6.2
Mean	5.0	4.8	4.9

Number in bracket estimated from analysis of variance

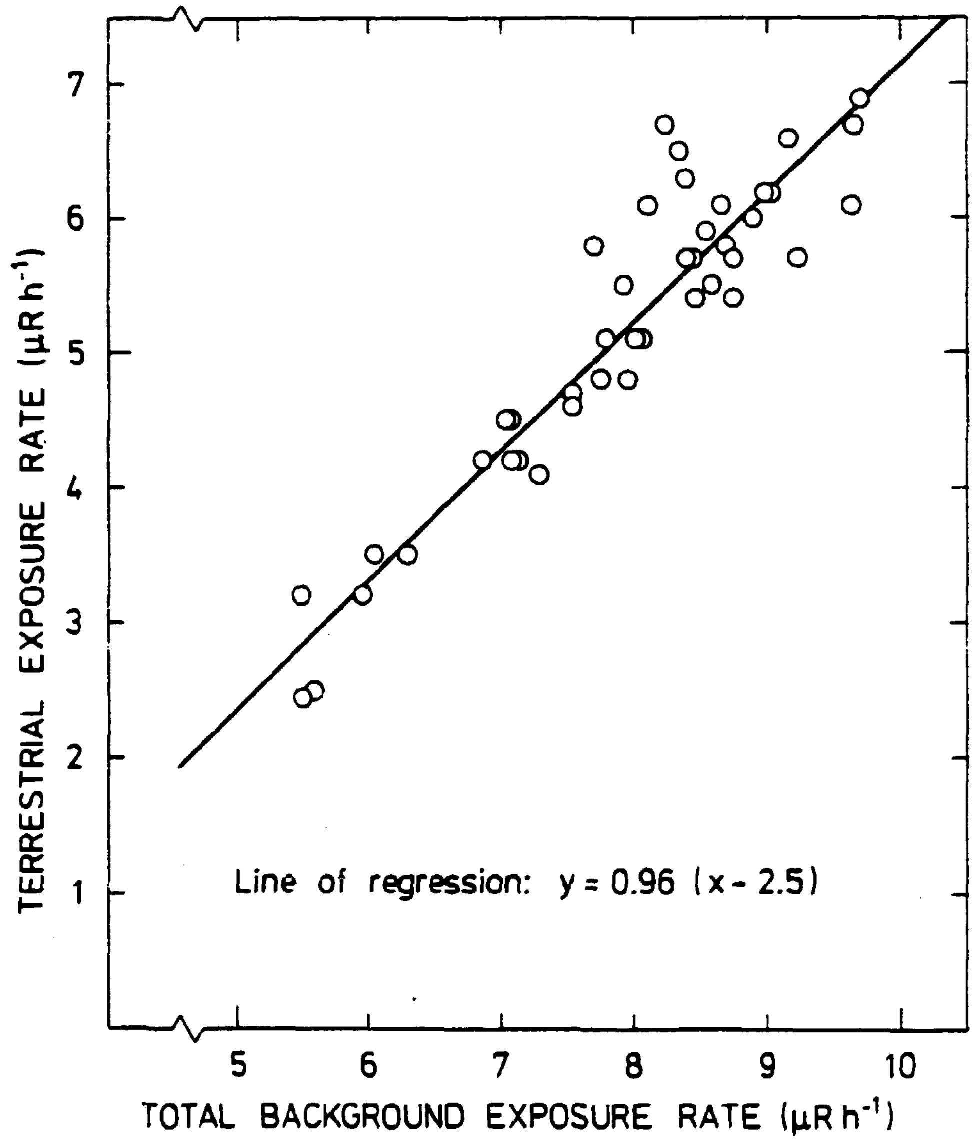


Fig. 4.3.1. Results of 11.4 x 5.1-cm NaI(Tl) detector measurements (μR h^{-1}) versus results of ionization chamber measurements (μR h^{-1}).

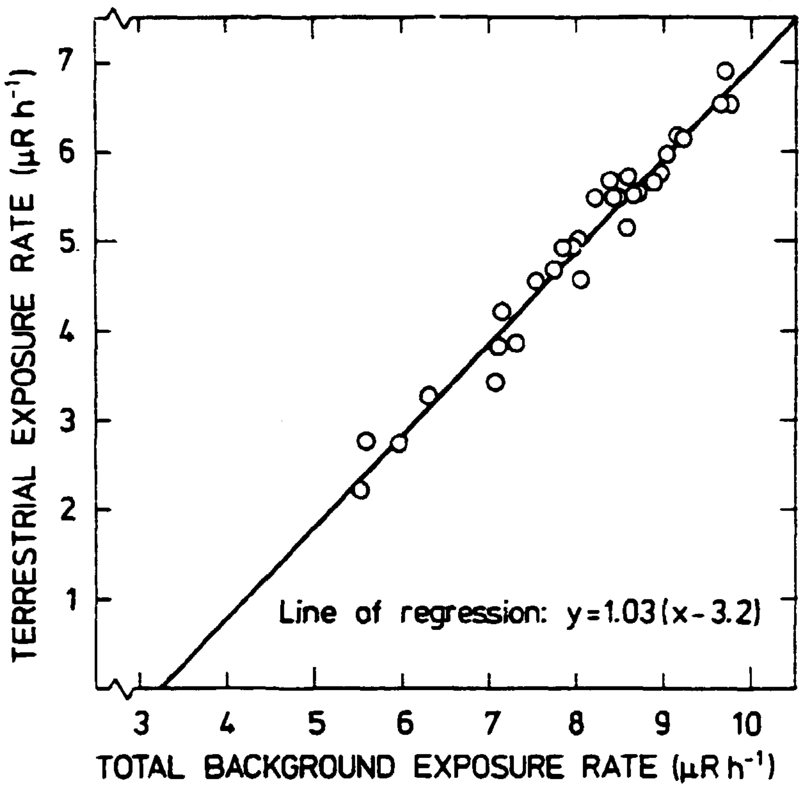


Fig. 4.3.2. Results of 7.6 x 7.6-cm NaI(Tl) detector measurements (μR h^{-1}) versus results of ionization chamber measurements (μR h^{-1}).

4.4. Ge(Li) detector results

Ge(Li) spectrometer measurements were made in June and September and the estimates of the terrestrial exposure rates from ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs are shown in Tables 4.4.1 and 4.4.2.

The total terrestrial exposure rates are depicted versus the ionization chamber measurements of the total background exposure rate in Fig. 4.4.1. The regression line is of the type $y = \alpha(x-\beta)$ which yields for the coefficients: $\alpha = 1.03 \pm 0.03$ μR h^{-1} per μR h^{-1} and $\beta = 3.8 \pm 0.1$ μR h^{-1}.

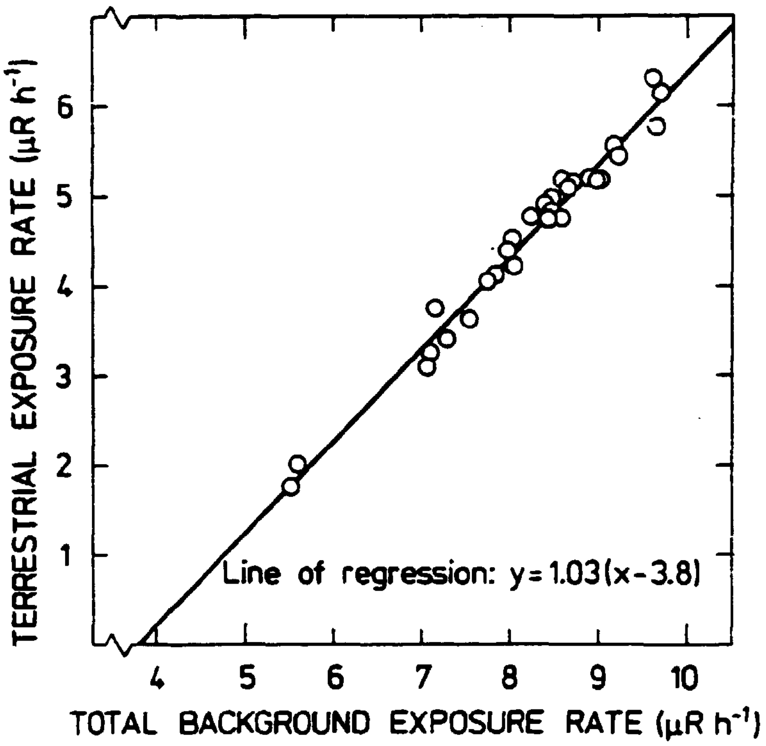


Fig. 4.4.1. Results of Ge(Li) detector measurements ($\mu R\ h^{-1}$) versus results of ionization chamber measurements ($\mu R\ h^{-1}$).

It is noted that the precision of the results is comparable to that of those from the 7.6 × 7.6-cm NaI(Tl) detector, and that the slope does not depart significantly from unity.

Estimates of exposure rates from the secondary cosmic radiation are obtained as the differences between the total background exposure rates measured with the ionization chamber and the total terrestrial exposure rates estimated from Ge(Li) detector measurements. These estimates of the secondary cosmic radiation and the corresponding atmospheric pressures measured with an aneroid barometer are listed in Table 4.4.3 and shown in Fig. 4.4.2, where a regression line of the type $y = \alpha(x-760) + \beta$ is fitted. The linear regression is highly significant and yields for the coefficients $\alpha = 0.016 \pm 0.003\ \mu R\ h^{-1}$ per mm Hg and $\beta = 3.56 \pm 0.03\ \mu R\ h^{-1}$.

Table 4.4.1. Terrestrial exposure rates estimated from field spectroscopic measurements made in June 1978 ($\mu R\ h^{-1}$).

Location	^{40}K	^{226}Ra	^{232}Th	^{137}Cs	Total
Tylstrup	2.1	0.6	0.9	0.1	3.8
Studsgård	0.8	0.4	0.6	0.9	2.7
Ødum	2.2	0.7	1.1	0.1	4.1
Askov	1.5	0.7	1.0	0.2	3.3
St.Jyndevad	1.0	0.4	0.3	0.1	1.8
Blangstedgård	2.3	0.9	1.4	0.1	4.8
Skydebanen	2.0	0.7	1.1	0.2	4.1
Risø	2.5	0.9	1.5	0.1	4.9
Ledreborg	2.4	1.0	1.5	0.1	5.0
Tystofte	2.2	1.6	1.3	0.1	5.2
Abed	2.3	1.0	1.7	0.1	5.2
Gudhjem	2.8	1.2	2.2	0.1	6.2
Tornbygård	2.6	1.1	1.8	0.1	5.6
Rødbjergkilde	2.3	2.0	1.9	0.2	6.3
Mean	2.1	0.9	1.3	0.2	4.5

Table 4.4.2. Terrestrial exposure rates estimated from field spectroscopic measurements made in September 1978 (μR h^{-1}).

Location	^{40}K.	^{226}Ra	^{232}Th	^{137}Cs	Total
Tylstrup	1.7	1.0	0.6	0.1	3.4
Studsgård	0.6	0.4	0.5	0.7	2.2
Ødum	2.1	1.0	1.1	0.1	4.2
Askov	1.3	0.8	0.9	0.2	3.1
St.Jyndevad	1.0	0.6	0.3	0.1	2.0
Blangstedgård	2.2	0.8	1.3	0.1	4.4
Skydebanen	1.8	0.7	1.0	0.3	3.6
Risø	2.3	0.9	1.5	0.1	4.8
Ledreborg	2.3	0.9	1.4	0.1	4.7
Tystofte	2.2	0.9	1.3	0.1	4.5
Abed	2.3	1.1	1.6	0.1	5.1
Gudhjem	2.7	1.1	2.0	0.1	5.8
Tornbygård	2.4	1.0	1.6	0.1	5.2
Rødbjergkilde	1.9	1.7	1.7	0.1	5.5
Mean	1.9	0.9	1.2	0.2	4.2

Table 4.4.3. Measurements of atmospheric pressure (mm Hg) and estimates of the secondary cosmic radiation (μR h^{-1}).

Location	Date	Atmospheric pressure mm Hg	Secondary cosmic radiation μR h^{-1}
Risø	780407	762	3.55
Gudhjem	780525	759	3.55
Tornbygård	780526	763	3.61
Rødbjergkilde	780526	766	3.31
Risø	780613	757	3.69
Tystofte	780614	757	3.39
Abed	780615	756	3.55
Blangstedgård	780616	755	3.46
Tylstrup	780619	757	3.39
Ødum	780619	756	3.72
St.Jyndevad	780621	752	3.75
Askov	780622	745	3.84
Røsnæs *)	780623	743	3.84
Ledreborg	780627	750	3.49
Skydebanen	780629	757	3.68
Risø	780630	757	3.49
Risø	780905	751	3.82
Skydebanen	780906	753	3.90
Ledreborg	780907	752	3.69
Abed	780908	759	3.56
Tylstrup	780911	736	3.89
Ødum	780911	733	3.83
St.Jyndevad	780913	760	3.57
Askov	780914	748	3.97
Gudhjem	780918	750	3.87
Tornbygård	780919	746	3.81
Rødbjergkilde	780919	753	3.78
Tystofte	780920	762	3.50
Blangstedgård	780921	759	3.57

*) Additional location

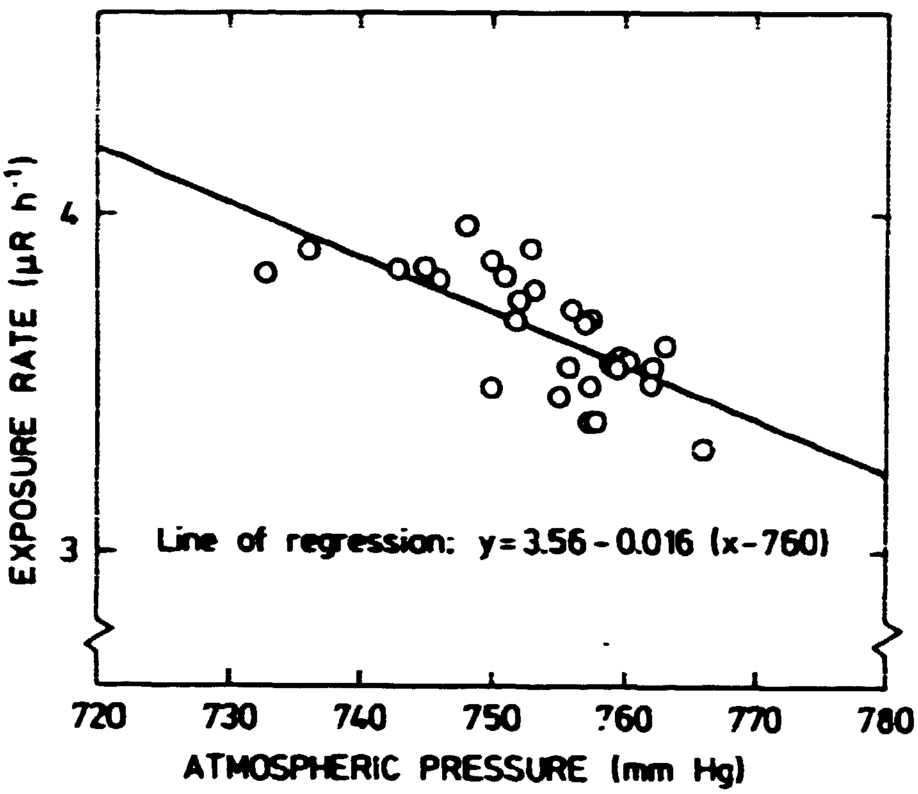


Fig. 4.4.2. Estimates of the secondary cosmic radiation (μR h^{-1}) versus barometric pressure (mm Hg).

The slope α expressed as a total barometer coefficient is 4.5 ± 0.9% per cm Hg, which compares well with other published values of this coefficient (Shamos and Liboff, 1966). Furthermore, the value for β agrees with that of the cosmic-ray ionization at sea level at an atmospheric pressure of 760 mm Hg (3.6 μR h^{-1}) adopted by UNSCEAR (1977).

It is noted in Tables 4.4.1 and 4.4.2 that the contributions to the terrestrial exposure rates from ^{137}Cs at Studsgård are unusually high. This is due to a covering of heather, which accumulates fallout and thus represents a source elevated above ground. The calculational model for interpreting the γ-spectra does not allow for such a source distribution, but it was possible at any rate, to estimate the ^{137}Cs exposure rate contribution. The contribution was estimated as the difference between the total background exposure rate and the sum of the terrestrial exposure rate from the naturally occurring radionuclides and the secondary cosmic-ray exposure rate. The validity of this calculational procedure was supported as in both cases the same ratio was obtained between the estimated ^{137}Cs exposure rate and the count rate in the 662 keV peak from the γ-spectrum. Using this technique it is possible to determine exposure rates in the environment from artificial radionuclides with an unknown distribution when simultaneous measurements are made with an ionization chamber, a Ge(Li) spectrometer, and a barometer.

During the field measurements made in June, soil samples were collected in plastic bags from the top soil layers (0-20 cm). No vertical profiles were taken. The samples were later transferred to tin cans and measured by Ge(Li) spectroscopy in the laboratory. These results referring to the in situ soil condition with regard to moisture were then compared with corresponding results from the field measurements. The results of the field and laboratory measurements are shown in Tables 4.4.4, 4.4.5, 4.4.6, and 4.4.7 for the radionuclides ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs, respectively.

A few results have been excluded from the comparisons. At Tystofte a heavy rainfall took place during the field measurements and caused a significant wash-out of radon daughters from the atmosphere to the soil surface. The short-lived daughters in the soil sample had decayed when the sample was measured in the laboratory. The opposite effect was observed at Rødbjergkilde, where the field-recorded γ-spectrum indicated a significant disequilibrium between ^{226}Ra and its short-lived successors. This disequilibrium was not observed in the soil sample due to the time lapse from sample taking to laboratory measurement. The Rødbjergkilde site is not typical as it is located near a well, said by local people to contain radium. All the sites except Studsgård and Skydebanen the soil was cultivated leaving the fallout ^{137}Cs homogeneously distributed in the plowing layer (0-20 cm), as is the case for the naturally occurring radionuclides. Therefore, it was not possible to compare the field and laboratory results for ^{137}Cs at Studsgård and Skydebanen.

The results of the laboratory measurements have been correlated with those of the field measurements and the correlations are depicted in Figs. 4.4.3, 4.4.4, 4.4.5, and 4.4.6 for the four radionuclides. The figures show the principal axes of correlation and none of the slopes of these lines deviates significantly from unity at the 5% level. The correlation coefficients are all highly significant and have the values 0.98 for ^{40}K, 0.94 for ^{226}Ra, 0.98 for ^{232}Th, and 0.84 for ^{137}Cs.

Table 4.4.4. Soil concentrations of ^{40}K (pCi g^{-1}).

Location	Field meas.	Lab meas.
Tylstrup	11.7	10.5
Studsgård	4.3	4.6
Ødum	12.1	10.7
Askov	7.9	8.1
St.Jyndevad	5.5	5.3
Blangstedgård	12.7	12.8
Skydebanen	10.8	10.2
Risø	13.8	13.4
Ledreborg	13.0	12.4
Tystofte	12.0	11.3
Abed	12.7	11.6
Gudhjem	14.7	14.4
Tornbygård	13.2	11.7
Rødbjergkilde	10.5	10.8

Table 4.4.5. Soil concentrations of ^{226}Ra (pCi g^{-1}).

Location	Field meas.	Lab meas.
Tylstrup	0.29	0.31
Studsgård	0.21	0.27
Ødum	0.35	0.30
Askov	0.36	0.38
St.Jyndevad	0.18	0.14
Blangstedgård	0.47	0.44
Skydebanen	0.38	0.34
Risø	0.51	0.46
Ledreborg	0.55	0.45
Tystofte *	0.84	0.42
Abed	0.53	0.53
Gudhjem	0.56	0.59
Tornbygård	0.53	0.48
Rødbjergkilde *	0.91	1.30

* excluded from correlation

Table 4.4.6. Soil concentrations of ^{232}Th (pCi g^{-1}).

Location	Field meas.	Lab meas.
Tylstrup	0.34	0.29
Studsgård	0.22	0.24
Ødum	0.40	0.36
Askov	0.35	0.35
St.Jyndevad	0.10	0.11
Blangstedgård	0.51	0.55
Skydebanen	0.41	0.43
Risø	0.58	0.61
Ledreborg	0.53	0.55
Tystofte	0.47	0.49
Abed	0.62	0.55
Gudhjem	0.70	0.76
Tornbygård	0.59	0.58
Rødbjergkilde	0.60	0.66

Table 4.4.7. Soil concentrations of ^{137}Cs (pCi g^{-1}).

Location	Field meas.	Lab meas.
Tylstrup	0.21	0.24
Studsgård	-	0.25
Ødum	0.22	0.17
Askov	0.26	0.27
St.Jyndevad	0.23	0.22
Blangstedgård	0.21	0.23
Skydebanen	-	0.29
Risø	0.15	0.15
Ledreborg	0.15	0.16
Tystofte	0.17	0.17
Abed	0.18	0.15
Gudhjem	0.13	0.15
Tornbygård	0.19	0.18
Rødbjergkilde	0.20	0.20

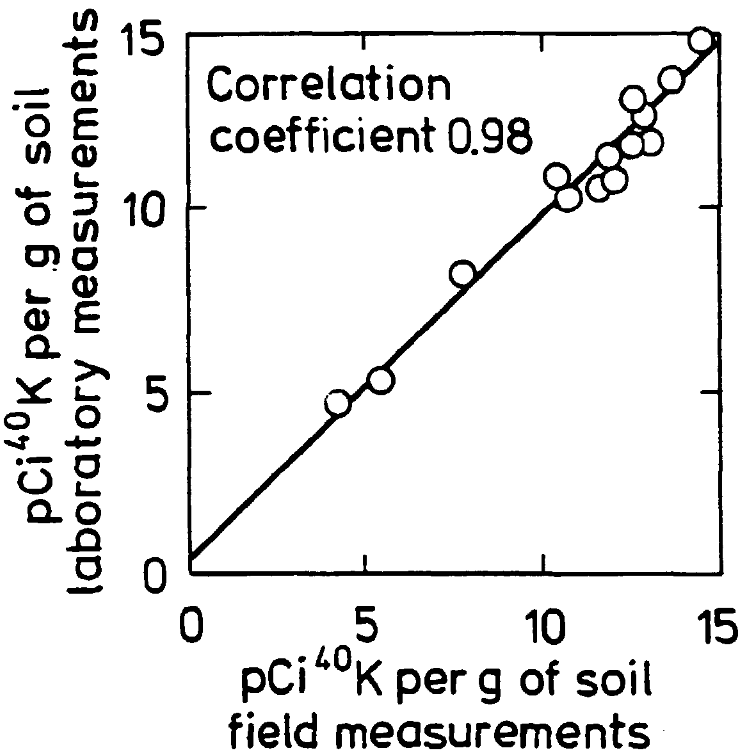


Fig. 4.4.3. Results from field measurements versus results from laboratory measurements of ^{40}K soil concentrations (pCi g^{-1}). The line indicates the principal axis of correlation.

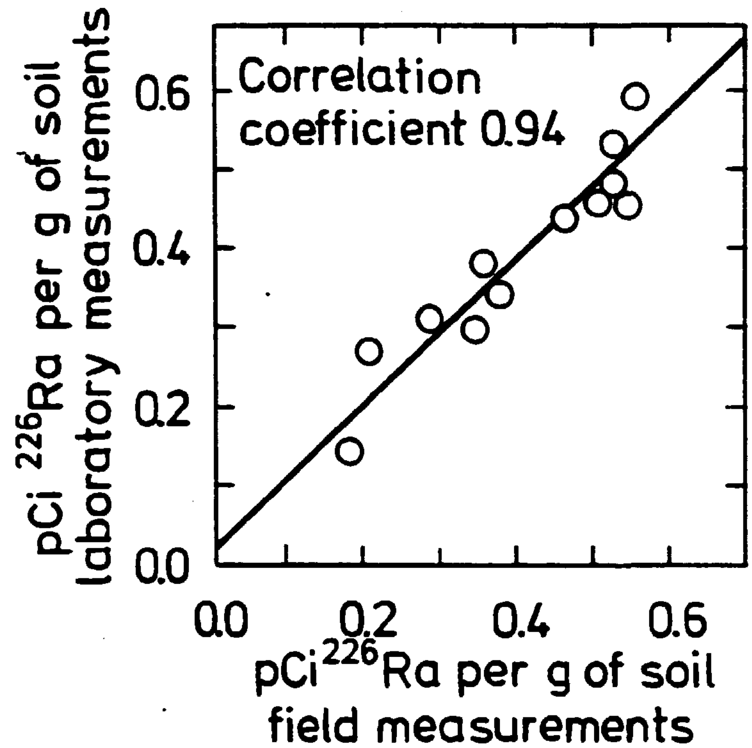


Fig. 4.4.4. Results from field measurements versus results from laboratory measurements of ^{226}Ra soil concentrations (pCi g^{-1}). The line indicates the principal axis of correlation.

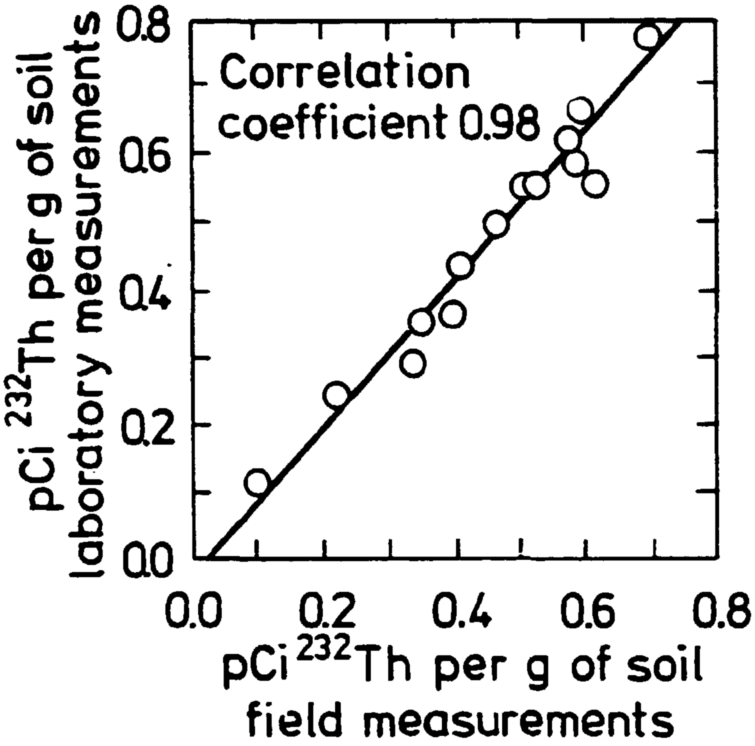


Fig. 4.4.5. Results from field measurements versus results from laboratory measurements of ^{232}Th soil concentrations (pCi g^{-1}). The line indicates the principal axis of correlation.

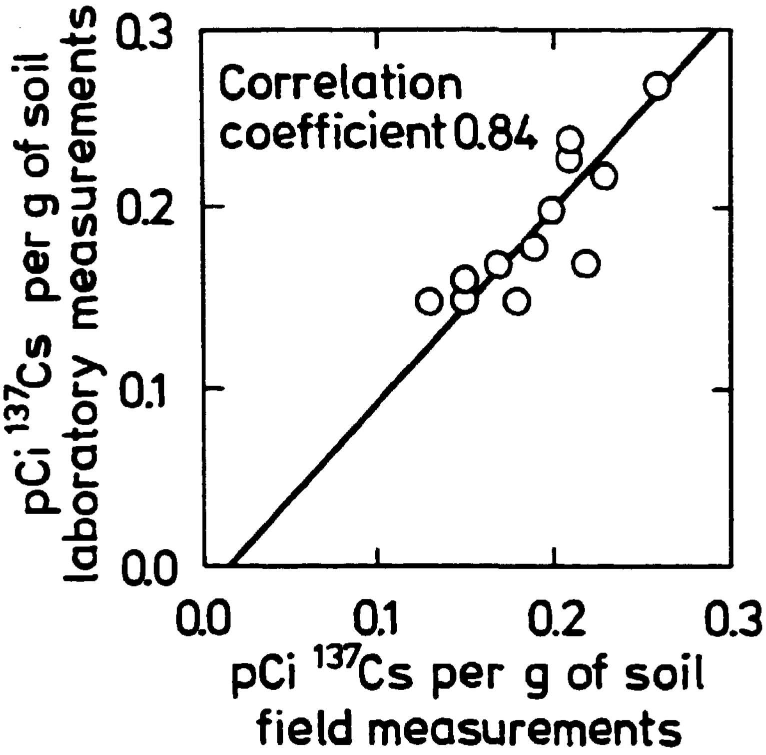


Fig. 4.4.6. Results from field measurements versus results from laboratory measurements of ^{137}Cs soil concentrations (pCi g^{-1}). The line indicates the principal axis of correlation.

5. DISCUSSION

The ionization chamber results were used as a basis for comparison with those of the other detectors for several reasons: The ionization chamber yields mean exposure rates with very high precision as they are calculated from a large number of observations. The results are thus well suited as abscissa values in regression analyses. Furthermore, the ionization chamber has a well-documented full response to the cosmic-ray component and to the terrestrial γ-ray component of the background radiation, and yields free-air-equivalent exposure rates.

Regarding the ionization chamber response to environmental γ-radiation, it is noted from Tables 4.4.1 and 4.4.2 that the potassium, thorium, and radium (uranium) mean exposure rates are in the ratios 0.5 : 0.3 : 0.2, which differ from those mentioned in Section 2.2. However, the response turns out to be invariant to this difference when the ionization chamber γ-ray energy response is folded with the actual γ-ray composition.

As mentioned previously, we found no statistically significant difference between the TLD results and those of the ionization chamber. Comparison of the results in Tables 4.1 and 4.2 may, however, indicate that the TLD results are a little higher on the average 2.5% than the ionization chamber results. A systematic difference of that magnitude could not be detected with statistical significance from the present investigation due to the limited number of observations and to the natural fluctuations of the total background exposure rate (see Fig. 4.2.2). The different γ-energy cut-offs of the two detector systems will, however, cause a small systematic bias. The γ-energy cut-off for the TLD is about 20 keV and for the ionization chamber about 70 keV. According to computer calculations of the terrestrial γ-radiation field (Kirkegaard and Løvborg, 1979), this difference could cause a higher TLD response (2-3%) compared with the ionization chamber.

Further work is being done in order to check the calibration of the ionization chamber by performing a so-called shadow-shield calibration. This procedure, which is described by DeCampo et al. (1972), has the advantage, compared to that mentioned in Section 2.2, that only the unattenuated γ-rays from the calibration source are considered. Thereby, the problems with the ground-scatter component and the energy distribution of that component are avoided.

The terrestrial exposure rates estimated from the Ge(Li) spectrometer measurements seem reliable, due to the satisfactory comparisons with the results of the ionization chamber measurements. The terrestrial exposure rates are estimated indirectly from the recorded γ-ray spectra using only information on the unscattered γ-ray flux density. But the results (Fig. 4.4.1) show that the calculated exposure rates compare very well with the measured exposure rates of the total background radiation.

Furthermore, the ability of an acceptable numerical value and variation with atmospheric pressure of the cosmic component to be derived from the measurements support the results of the ionization chamber system. The comparison of the radionuclide concentrations in the soil also show that reliable estimates of radionuclide concentrations can be obtained from Ge(Li) spectroscopic measurements in the field provided the source material is homogeneously distributed in the ground.

The results of the NaI(Tl) detector measurements overestimate the terrestrial exposure rates due to the inherent detector background count rate mentioned previously. Empirical corrections can be obtained by comparing the detector measurements with the ionization chamber results. From Table 4.1 the average value for the total background radiation for all the measurements is 7.9 μR h^{-1}. By subtracting the cosmic component of 3.6 μR h^{-1} an average value of 4.3 μR h^{-1} for the terrestrial component is obtained. This value can be compared with the corresponding average values in Tables 4.3.1 and 4.3.2. This indicates that the two NaI(Tl) detectors overestimate the terrestrial exposure rate with 0.9 and 0.6 μR h^{-1} for the 11.4 × 5.1-cm detector and 7.6 × 7.6-cm detector, respectively.

6. CONCLUSION

Measurements of the background radiation were made in 1978 at 14 locations with TLD's, an ionization chamber, two NaI(Tl) detectors, and a Ge(Li) spectrometer system. The purpose was to compare the instrument results in order to obtain information on the applicability of the different instruments for measurements of the background radiation.

The ionization chamber measures the total background exposure rate with high precision. The accuracy is believed to be good, as a value of 3.6 μR h^{-1} was obtained for the secondary cosmic-ray contribution at ground level in agreement with the value adopted by UNSCEAR (1977). This was accomplished because of the reliable estimates of the terrestrial exposure rates from measurements made with the Ge(Li) spectrometer system. These measurements showed also that reliable estimates of radionuclide concentrations in the soil can be obtained from field measurements, provided that the source material is homogeneously distributed in the ground.

The investigation shows that the TLD's yield reliable estimates of the mean total background exposure rate, in agreement with the ionization chamber results.

The NaI(Tl) detector results show that accurate estimates of terrestrial exposure rates can be obtained with these detectors if empirical corrections are applied. The precisions of the results for the detector operating with a counting threshold at about 0.4 MeV are comparable with those of the results from the Ge(Li) spectrometer system whereas the precision for the detector with a threshold at about 0.02 MeV is much poorer.

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AN INTERCOMPARISON OF DETECTORS FOR MEASUREMENT OF BACKGROUND RADIATION

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Abstract

Measurements of the background radiation were made in 1978 at 14 locations with a high-pressure ionization chamber, thermoluminiscence dosimeters (TLD's), two NaI(Tl) detectors, and a Ge(Li) spectrometer system. Simultaneous measurements with the ionization chamber and the spectrometer system provide reliable estimates of the total background exposure rate, of the individual contributors to the terrestrial exposure rate, and of the exposure rate from the secondary cosmic radiation. The TLD results agree with those of the ionization chamber. The NaI(Tl) detector results show that accurate estimates of the terrestrial exposure rate can be obtained if empirical corrections are applied.

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